Rectifier ICs

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Using a Current Monitor to Create an Elegant Precision Rectifier Design

Classic precision rectifier designs suffer from factors such as a high component count, resistor synchronization issues, and a double-ended power requirement. Here is one way to address those concerns.

Traditionally, precision full wave rectifiers[1] used in a range of instrumentation applications have employed between seven and nine discrete circuit components. These are typically two op-amps, two diodes and three to five resistors. This article will show that an alternative approach, using a standard current monitor IC, reduces the component count to just five and greatly simplifies circuit configuration, producing a more elegant overall solution.

Why is a precision rectifier required? Since a diode has a forward voltage drop of typically 0.6V, any signal not an order of magnitude larger than this will suffer major distortion. The problem is exacerbated for full wave rectification, where the signal must overcome two diode drops.

Even a voltage as 'large' as 10V will suffer significant distortion when full-wave rectified using diodes with at least 12 percent of the signal being subjected to severe distortion. Quite often however, the signal to be rectified is far less than 1V.

Illustrated in Figure 1, classic solutions used to address this problem feature diodes in the feedback path of an operational amplifier (op-amp). This effectively changes the normal diodes into near perfect diodes, i.e. devices that conduct unidirectionally with zero forward voltage drop.

To better appreciate the advantages offered by the proposed current monitor based design, the operation of the classic precision full wave rectifier shown in Figure 1 is best considered first. Inspection shows the following.

For positive inputs, the transfer function is:

Equation 1

For negative inputs, the transfer function is:

$$V_{OUT} = +V_{IN}\left(\frac{R2}{R1}\cdot\frac{R5}{R3} - \frac{R5}{R4}\right)$$

Equation 2

There is therefore asymmetry in the transfer

$$V_{OUT} = +V_{IN}\frac{R5}{R4}$$

functions for the two halves of the signal, and the circuit can only work provided that

Equation 3 **Equation 4**

$$\frac{R2}{R1}\cdot\frac{R5}{R3} = 2\cdot\frac{R5}{R4} \quad \text{Or} \quad \frac{R2}{R1}\cdot\frac{R4}{R3} = 2$$

Equation 4 shows that both the absolute values and ratios of resistors R1 to R4 are critical to satisfactory performance of this circuit. It also shows that there are two ways that the values could be arranged for precision rectification to take place. One way, shown in Figure 1, is to make R1, R2 and R3 the same value (R), and then make R4 and R5 equal to 2R for unity gain. The other way is to make R1, R3, R4 and R5 the same value (R), and then make R2 equal to 2R. This second option, while it works OK, will have a slightly reduced bandwidth compared to the first and is therefore not the preferred option. The effect of R5 in both cases is to apply an overall gain to the circuit. Its absolute value is not important as long as the condition given by Equation 4 is satisfied. This will only be the case if close tolerance resistors are used.

The major drawbacks of this classic precision rectifier design can therefore be summarised as follows:

1. Component count comparatively high.
2. Good performance depends on getting four resistors in perfect balance.
3. Requires a double-ended power supply.

A Current Monitor Based Precision Rectifier

In contrast, the proposed alternative method based around a current monitor IC avoids the problems outlined above.

The current monitor is normally used to provide bi-directional current monitoring. It produces an amplified output (gain = 10) that is always positive regardless of the polarity of the voltage across its S+ and S- terminals (sense voltage or V_{SENSE}). This sense voltage is normally derived by using a sense resistor (R_S) in series with the load in order to make V_{SENSE} proportional to the load current.

Consider the current monitor's use in the alternative precision full wave rectifier circuit shown in Figure 2. Here, resistors R1 and R2 provide DC bias for IC pins S+ and S-, respectively. Pin S- is decoupled by C2, effectively making it an AC ground. This means that any signal that is coupled onto pin S+ will appear across pins S+ and S- as sense voltage. This voltage is then amplified by the current monitor, which also produces a unipolar output. It is therefore an amplified full wave rectification of the AC component of the input voltage.

Very Low Level Signals

Signals as low as 10mV or less can also be precision rectified by the circuit. Some limitations, however, need to be considered.

The less important of these is the differential input offset voltage of the device. This is the net difference between the input offset voltage in the forward and reverse direction. This difference is added to the rectified signal in one direction and subtracted in the other.

1. The net effect of this distortion on the average value of the signal is nil.
2. The effect is easily cancelled out by simple input offset trimming, resulting in an improved waveform.

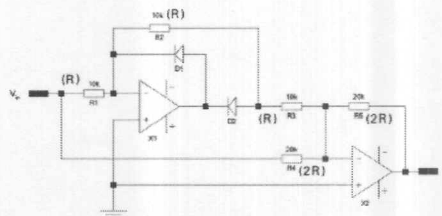

Figure 1. A classic precision full wave rectifier (nine components).

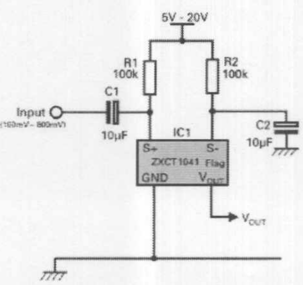

Figure 2. A current monitor based precision full wave rectifier.

The more important limiting factor has to do with the internal design of the current monitor and is more difficult to solve. This is the crossover distortion which is introduced when the current monitor IC changes from conducting in one direction to conducting in the opposite direction.

Inside the current monitor is a pair of amplifiers connected in anti-parallel mode. There is a delay between one amplifier switching off and the other taking over when the input changes polarity. This delay is quantified on the current monitor's datasheet[2] with graphs showing typical delays for small and large signals. The delay can be as long as 8 µs including the effects of output slew rate.

In general, all these effects are more dominant and visible only at very low input voltages (<100 mV). They are less conspicuous at higher input voltages (>100 mV). Together, they impose a limit on the bandwidth that is achievable by the circuit. When operated in the unipolar mode with suitable DC bias, this device is capable of a bandwidth of 300 kHz. However, the achievable bandwidth in this case has been limited to about 25 kHz due to the factors outlined above.

Conclusion

A precision full wave rectifier can be implemented using a bi-directional current monitor. Requiring just five components, it offers the advantage of significantly reduced component count over classic two op-amp methods. The savings in PCB real estate is even greater because the single active element is housed in a SOT23-5 package compared with the much bigger SO8 package often used for dual op-amps.

The circuit uses only two resistors and two capacitors, and its performance is not adversely affected by the absolute values of these components. A good match is still recommended for the two resistors, though 1 percent tolerance resistors are sufficient for this purpose; precision components are not required.

Unlike the classic circuit that requires both a positive and negative supply, this circuit only uses a positive power supply.

Lastly there is the added advantage that the current monitor based rectifier offers an inherent ability to block DC components in the signal. The classic approach requires yet another component to achieve blocking.

References

1. The Art of Electronics, Paul Horowitz and Winfield Hill, Second Edition.
2. Zetex Semiconductors Application Note 39 (AN39) - Current Measurement Applications Handbook.
3. Datasheet ZXCT1041.

For More Information

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